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Light addressable potentiometric sensor array: a new approach for light beam positioning

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Abstract

An analytical system for multicomponent analysis of liquids based on a light addressable potentiometric sensor (LAPS) with an array of ion-sensitive polymer membranes is presented. A developed LAPS device is based on a BESOI wafer which permits easy fabrication of a sensor with thin silicon membrane and enhanced spatial resolution. To generate the photocurrent the backside silicon was illuminated using a new technical approach based on a DLP (Digital Light Processing) chip used in video projectors. When a DLP chip is coordinated with a digital graphic signal, a light source, and a projection lens, its mirrors can reflect a digital image onto the LAPS surface. The developed system is shown to be able to produce light spots down to 50 µm in diameter and perform measurements at different points with programmable coordinates. To prove the functionality of the proposed method a LAPS sensor array with 60 ion-sensitive membranes of three different types was tested.

Keywords: LAPS; sensor array; multicomponent analysis; electronic tongue

1. Main text

LAPS devices gained much interest [1, 2] as they give a possibility to build a chemical sensors array of high density (several hundreds on a square centimetre) on a small area. To perform measurements at different chemically active sites on a LAPS surface precise positioning of a laser beam at each point is needed which requires rather expensive micropositioning systems. Another option is to use independent light sources but this reduces the overall density of the array. In the present work a new method of light beam positioning is proposed.

1.1. New concept of the light positioning

An array of 40 laser diodes with a 470 nm wavelength and 3 watts total power was used as a light source to illuminate a DLP chip from a standard video projector. Designed optical system projected the image from the DLP chip as a rectangle of 20 x 15 mm on the backside of the LAPS chip. From a computer a graphical image of a white

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spot on a dark field is sent to the DLP chip which is projected onto the LAPS. With a sequence of images it is easy to vary coordinates of the light spot and perform the photocurrent measurements at different sites of the sensor array. The experimental set-up is schematically presented in Figure 1. The optical system was configured so that the overall projected widow had the size of 10x8 mm. At the projector resolution of 800x600 pixels each pixel (DLP micromirror) projected a 12,5 x 13, 3 micrometer spot on the LAPS surface. Thus, this light spot size is the optical limit of the system. Taking into account a significant decrease in the light beam power when only one micromirror is used, in practice the special resolution is limited to 50-60 microns when 4x4 micromirror array is used.

To test the performance of the system 60 polymer membranes 250-350 µm in diameter and 100-150 µm thick of three different membrane compositions sensitive to sodium, potassium and chloride ions were deposited [3] on the Si_3N_4 –SiO_2-Si LAPS chip fabricates on a BESOI wafer with a 20 µm thick working silicon layer. The distance between membranes was fixed at 900 µm (Figure 2).

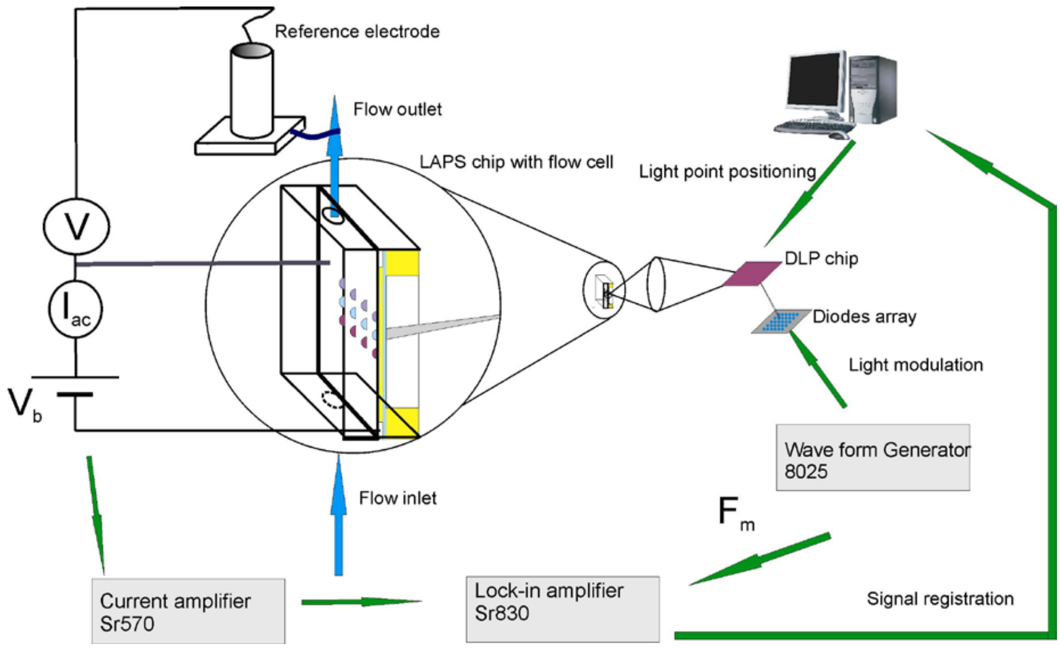

Fig.1. Schematic drawing of the experimental setup. The laser diodes (LD) light was modulated by voltage from a waveform generator (WFG) (Tabor Electronics model 8025) and was projected as a small spot with known X-Y coordinates onto the LAPS device. Resulting photocurrent was registered by a low noise current amplifier (Stanford Research Systems SR570) which has a built-in source of voltage V_b used to control the biasing of the LAPS. The amplified ac current transformed into ac voltage with frequency F_m was registered by a lock-in-amplifier (Stanford Research Systems SR830) and the output signal was acquired by a computer through a GPIB port.

1.2. Preparation and deposition of ion-selective membranes

To prepare ion selective membranes a 0.3 g of the main polymer composition mixture (polyurethane diacrylate, cross-linker and photoinitiator) was dissolved in 0.2 ml of tetrahydrofuran and to this solution ionophore, plasticizer and lipophilic salt were added. The exact composition of Cl^-, K^+ and Na^+ membranes are presented elsewhere [3]. The mixture was thoroughly stirred in an ultrasonic bath until homogeneous and then was left for several hours to evaporate the solvent. All other chemicals used were analytical-reagent grade. Standard solutions were prepared with deionised water.

To enhance the adhesion of the encapsulating polymer and the membrane to LAPS surface, wafers with chips were preliminarily silylated by spin-coating of 10% (v/v) (methacryloxy) propyltrimetoxysilane solution in ethanol with a subsequent heat treatment during 1 hour under 80°C in an oven. The membrane cocktails were deposited by a microdispenser with 5 micrometers precision of the positioning in three directions. Before deposition three small vessels with volumes about 1 µl for each membrane type (sodium, potassium and chloride) were prepared. The dispenser needle contacted one of the solutions in these vessels and then translated the drop of the membrane cocktail to the chip surface. This operation was repeated to form an array of membranes on the chip surface. Position of each membrane and their distribution on the chip was programmed using commercial software (Stepfour GMbH, Salzburg, Austria). This map was used afterwards to locate each membrane to perform the photocurrent measurements.

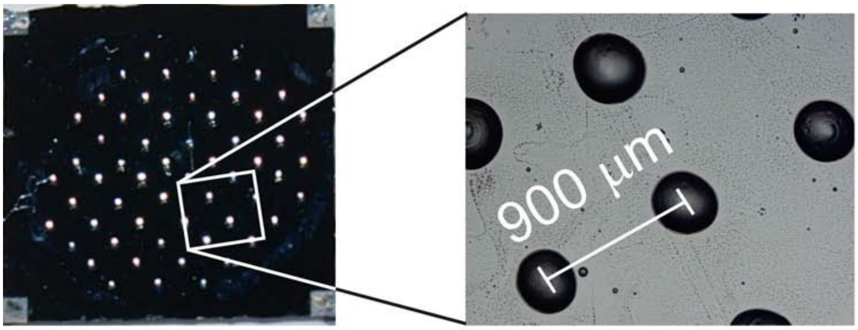

Fig.2. Photo of the LAPS chip (10 mm X10 mm) with 60 deposited ion selective membranes

1.3. LAPS response in pH buffer solutions

Silicon nitride deposited on the surface of the LAPS chip may be used as a pH-sensitive layer. For signal registration the chip surface were illuminated by light spots projected by 0x0, 10x10 и 20x20 micromirrors that corresponded to the spot size on the LAPS surface 0 x 0, 125 x 133 and 250 x 266 micrometers, respectively. Corresponding photocurrent-voltage curves measured in solution with pH are presented in figure 3a. As expected, the maximum current value depends on the spot size. It may be noted that the response at a spot size of 0 x 0 practically coincides with that of 125 x 133 µm. Thus, with this spot size the response comes not from the illuminated spot but is due to the background illumination of the entire surface. DLP micromirrors are working not in a static but in a dynamic mode and even when the entire surface is visually dark some light from laser diodes falls on the chip. The light power from the spot size 250 x 266 µm is sufficient for practical registration of the photocurrent and may be used for scanning of the surface. Typical LAPS response for silicon nitride membrane measured in solutions with different pH is shown on the Figure 3b.

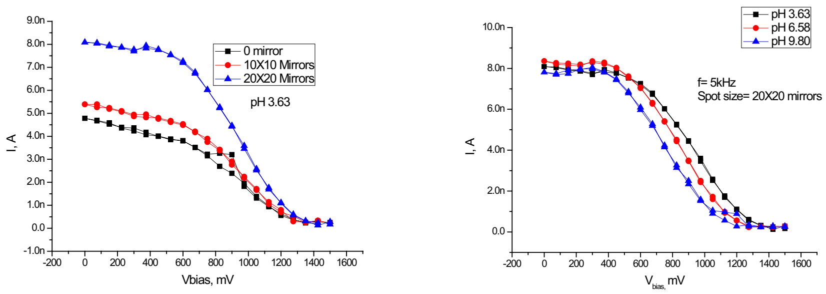

Fig.3. Current–voltage characteristics of the LAPS with silicon nitride insulator. A) measured at pH 3.63 and different spot size; B) measured with spot size of 250 x 266 µm at different pH values

1.4. Determination sodium, potassium and chloride in mixed solutions

Figure 4 shows examples of the response of three different sensors measured in NaCl and KCl solutions.. It may be noted that the maximum current is not the same for different membrane compositions and much lower than in case of bare silicon nitride surface. This is associated with the fact that electrical resistance of deposited membranes differs from one to another and this resistance through which the photocurrent passes limits its maximum value.

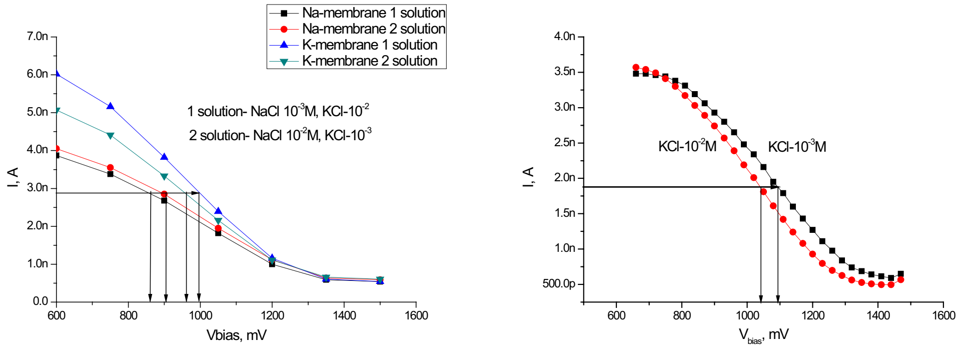

Fig.4. Current–voltage characteristics and chemical response of LAPS with sodium, potassium (on the left) and chloride membranes in mixed solutions of NaCl and KCl..

Conclusion

A new technical approach for characterization of LAPS-based chemical sensors is presented. To generate the photocurrent the backside silicon is illuminated by a laser diode array light source using a DLP (Digital Light Processing) chip typically employed in video projectors. When a DLP chip is coordinated with a digital graphic signal, a light source, and a projection lens, its mirrors can reflect a digital image onto the LAPS surface. The developed system is shown to be able to produce light spots down to 50 µm in diameter and perform measurements at different points with programmable coordinates. To prove the functionality of the proposed method a LAPS sensor array with 60 ion-sensitive membranes of three different types was tested.

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